AC AND DC BIPOLAR VOLTAGE SOURCE USING QUANTIZED PULSES

This application claims the benefit of the U.S. Provisional Application No. 60/091,639 filed Jul. 2, 1998.

This invention relates to a circuit for waveform generation wherein arrays of Josephson junctions are biased by combining a broadband two-level digital code and a sinusoidal frequency to produce a highly accurate bipolar voltage source.

BACKGROUND OF THE INVENTION

A wide variety of instrumentations exist to measure voltage. All of these instrumentations must be calibrated to provide accurate measurements. In the field of ac and dc metrology, instruments are devised to provide exact measurements of voltage so that other instruments can be calibrated to them. The Josephson junction has been utilized in metrology to take advantage of its quantum mechanical characteristics wherein time integrated areas of every generated voltage pulse are exactly the same regardless of the shape of the pulse as long as the device is driven at or above the critical current. When biased with a sinusoidal microwave frequency f, each junction exhibits constant voltage steps at $V=nf/K_J$. The Josephson frequency to voltage ratio K_J is a defined constant equal to 2 e/h which is the ratio of twice the electron charge and Planck's constant. K_J is equal to 483,597.9 GHz/V. When biased on each nth step, a junction generates exactly n quantized voltage pulses for each microwave period. For an array of N junctions, the time average dc voltage of the n^{th} step is $Vn=nNf/K_J$ where N is the number of Josephson junctions.

Synthesized voltage sources utilizing Josephson technology have been proposed and developed for unipolar ac and dc voltages that control pulses of a single polarity. The object of this invention is to devise a Josephson circuit for accurate, stable, arbitrary waveform generation with a predetermined frequency spectrum which will enable synthesis of both ac and dc bipolar waveforms where voltage pulses of both positive and negative polarity are precisely controlled and used to increase the output voltage.

SUMMARY OF THE INVENTION

Briefly stated, this invention is a circuit which provides a Josephson junction or series array of junctions driven with the combination of a sinusoidal microwave frequency and digital pulses. The digital pulses correspond to the mathematical model of a desired waveform. That waveform may be an ac waveform or any dc waveform that can be generated using a digital code of appropriate pattern and length. The combination of the sinusoidal drive and the digital pulses is used to current bias a Josephson quantizer. Output of the quantizer is fed into a standard filter to remove unwanted noise and thereby produce the desired waveform. Knowledge of the digital code, the drive frequency and the number of Josephson junctions is sufficient to precisely calculate the waveform output and in that manner enable highly accurate physical reproductions of the mathematical model.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. **1** and **2** show prior art circuits for physically synthesizing a waveform corresponding to a mathematical model.

FIG. **3** illustrates the circuit of this invention.

FIGS. **4** and **5** show the combination of waveforms in producing a drive signal for the Josephson junction quantizer of FIG. **3**.

FIGS. **6** and **7** show experimental results for the circuit of FIG. **4**.

DETAILED DESCRIPTION

When reference is made to the drawing, like numerals indicate like parts and structural features in the various figures.

FIG. **1** shows a prior art circuit for synthesizing a physical waveform from digital pulses which correspond to an input mathematical model. In FIG. **1** a mathematical model of the desired waveform **10** is input to a computer **11** in which a modulator algorithm is used to produce a sequence of zeroes and ones, that is, a digital code corresponding to the input waveform. The digital code can be generated to that number of binary decimals needed to obtain the accuracy desired. A digital code generator **12** receives the output sequence of the modulator algorithm for storage in its memory and utilizes that sequence to generate a two-level electrical signal which is a physical signal representing the digital code. Since that code corresponds to the mathematical model **10** of the desired waveform when the two-level signal is passed through an analog low pass filter **13**, a physical representation of the mathematical model is produced at **14**.

The circuit of FIG. **1** has been in use for many years but it leaves much to be desired in producing an output **14** which is exactly the same as the mathematical model **10**. The semiconductor digital code generator **12** cannot perfectly reproduce the ideal digital code because of voltage variations in its levels and phase or timing variations in transitions between levels. Those variations prevent the digital code generator from synthesizing a signal of metrological accuracy. For example, if a sine wave is desired, the output **14** would not correspond exactly to the mathematical model of a sine wave, and consequently cannot be utilized as a highly accurate standard circuit for metrology purposes.

FIG. **2** is a prior art circuit providing a significant advance over the circuit of FIG. **1**. In FIG. **2**, a Josephson pulse quantizer **15** is provided to receive the digital code input. As mentioned above, the output of the digital code generator **12** is a two-level signal which rises from a zero level to a plus one level but does not produce an ideal two-level digital code because of small variations present in the code generator output. However, in using the Josephson pulse quantizer **15**, the imperfect output of the code generator **12** is converted to a perfectly quantized output. The accuracy of the circuit is based on the fact that Josephson junctions generate voltage pulses whose time-integrated areas are perfectly quantized, that is, the area under each voltage pulse is equal to every other area under a voltage pulse, even though there may be some variation in the shape of the voltage pulses due to the imperfect input. Appropriate sequences of these quantized pulses are sent through a low pass filter to generate ac and dc waveforms with precisely calculable rms voltage. Applications of the device include (1) the generation of digitally synthesized ac signals with calculable rms voltages; (2) characterization of digital to analog (d/a) and analog to digital (a/d) converters; (3) calibration of dc and ac reference standards and volt meters; and (4) synthesis of low-phase-noise radar signals. U.S. Pat. No. 5,812,078 to Przybysz et al., incorporated herein by reference, shows circuits based upon the technology of FIG. **2**. U.S. Pat. No. 5,565,866, also incorporated herein by reference provides selectable arrays of Josephson junctions for producing a desired output voltage.